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Enhancement of presence in a virtual sailing environment through localized wind simulation

Jouke C. Verlinden*, Fabian A. Mulder, Joris S. Vergeest, Anna de Jonge, Darina Krutiy, Zsuzsa Nagy, Bob J. Logeman, Paul Schouten

Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628 CE, Delft, the Netherlands

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Abstract

In the context of sailing, wind plays an important role. However, there is little knowledge on how wind influences presence – the sense of "being there" - while immersed in a virtual setting. This article explores several wind parameters and presents a wind array to explore presence in a sail simulator. The simulation offered a virtual training track with a large-scale visualization, rudder input and haptic feedback on the main sheet line. In a controlled experiment, 10 participants tested the setup with and without wind; the results indicate that the wind contributes to presence and the level of engagement. Future setups address cover fan power, noise and wind temperature.

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Keywords: Wind simulation; sail simulator; sports training; presence

1. Introduction

Virtual reality is a relative new way for athletes to train; in this way it is possible to attain specific situations might be difficult to recreate in real life. The wind sensation is sometimes crucial in outdoor sports performance and should be considered in devising high-performance simulators. Furthermore, informal observations we found that top athletes sometimes sail with their eyes closed, reyling on the other senses while keeping an optimal course.

* Corresponding author. Tel.: +31-152789321.
E-mail address: j.c.verlinden@tudelft.nl

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There have been a number of wind simulation systems, yet little is known on their use when the participant is engaged in physical exercise such as sailing. It is expected that a realistic airflow enhances the immersion of a sail simulation. In training situations, this might lead to a better learning experience.

Similar to a prior experiment to investigate qualitative experience of motion on sailing simulation [1], our aim is to explore the fidelity and utility of wind. The target audience for this paper is the sports simulation and training community and researchers in the field of presence in virtual environments. After discussing related work on wind generation, exploratory experiments treat various aspects of wind perception in the context of sports. Based on these findings, a comprehensive sail simulator setup was developed. The results consider the influence on the sailing experience and the presence – the sense of „being there" - perceived by the sailors, followed by a discussion on the robustness of the data. We will end with conclusions and recommendations for future implementations.

1.1. Background

Sailing simulators are being proposed and built since the 1960s. One of the earliest inventions was filed by P. Hansen in 1965 as a US Patent, describing a boat hull rotatable about its longitudinal and vertical axes, remotely controlled to affect the heeling of the boat [2]. The device was meant for amusement and training purposes. Wind generation was also part of the invention, implemented by a fixed fan. Strange proposed a similar device in 1971 [3]. Obviously the wind is a crucial factor, accounted for in most computerized simulation models. However, simulation of the wind hitting a sailor and providing him/her with the sensation of air flow is not common. The ventilators in the designs of Hansen and Strange would give some experience of wind to the user of the device, but the wind would be steady and not well controlled. Mainly driven by the amusement industry several simulators have been developed that incorporate artificial wind, for example to enhance virtual roller coaster rides. Adjustable fans are typically used to accomplish this.

For sailing simulation the significance of wind is not only its propulsion of the boat, but its strength, direction and variability as it hits the sailor's face might be a cue that is crucial for ship control. The importance of wind experience was noted by Simonnet et al. who researched auditory tools and tactile maps that blind people need to sail autonomously [4]. For blind sailors the wind could be a disturbing factor or they might exploit it in some situations; these issues should be further studied in virtual environments according to Simonnet.

To achieve wind experience in a virtual environment there are two principles, one is based on fans fixed to the ground and the other is head mounted. The TreadPort Active Wind Tunnel from Kulkarni et al. [5] consists of one fan and valve-controlled air outlets. The system is combined with immersive cave automatic virtual environment (CAVE) and as such it functions as a multi-purpose virtual environment. The WindCube [6] was designed to improve the degree of immersion as felt by a user of VR systems. Their setup consists of multiple fans located on the ribs of a rectangular structure. The airflow generated is counting as an extra modality, besides audio, video and tactile. If the user is moving, the wind that should be perceived is computed and made real by controlling the individual fans over time.

Munakuchi addresses one of the problems that are faced when designing a wind system: the lag that is caused by the airflow generator [7]. Starting the engine and the distance the air particles will have to travel from the source to the point of tactility are two significant delay factors.

To minimize the distance, some researchers have developed head-mounted wind generation systems, for example [8]. The wind force experienced by the user is achieved by tuning the individual fans according to the movements in virtual space. Tests of this system showed that the simulated wind strongly contributed to the sense of immersion. The latency due to the inertia of the fans is mentioned in the paper as an issue for further development. A more compact design to produce localized wind sensation was presented by Kojima et al. [9]. The wind is produced by small loudspeakers, which makes the airflow controllable with fast response. Small hoses lead the air to locations near the user's ears, where the sensitivity to wind is high. It is important to make the device less noticeable for the user since this would only be distracting or emphasizing the in authenticity of the system [6].

1.2. Preliminary tests

As little is known about wind perception during outdoor activities, we conducted a pilot study to gain some main characteristics for the simulation system (Table 1). This included participants in various setups to measure wind direction and the presence of wind. One important observation is that all participants in this study felt that wind does increase the presence and that wind speeds do not have to be extreme as in real life. This latter is crucial: realistic wind forces require large power consumption (e.g. gale wind force 7 = 14 m/s, equaling to at least 2,3 kiloWatts).

Table 1. Wind perception characteristics from pilot study

Perceptual characteristic	Participant Setup	Task	Average value	Remarks
Minimal wind speed to feel immersed	Seated, head-mounted display with rollercoaster movie	Evaluate quality of experience	3 m/sec	
Sensitivity to changes in wind speed	Bike trainer, wears head-mounted display	Bike & count objects in a video. Raise hand when wind is changing (n=6)	0.3 m/sec	Less sensitive when airflow was slow.
Angular resolution in vertical plane	Seated, ears & eyes covered	having to point at percieved wind (n=6)	±45 deg	
Angular resolution in horizontal plane	Seated, ears & eyes covered	having to point at percieved wind (n=6)	±45 deg	Professional sailor: ±22,5 degrees.

2. Development of a wind array

Based on the pilot study results, we developed a sail simulation setup that includes wind simulation. The airflow was provided from an octagonal PVC structure, eight automotive fans were attached in the middles of the octagon's sides. Fans had an airflow rate of 2150 CFM with a diameter of 406 mm. Based on the previous findings, the fan array supplied directional flow from 8 directions, cf. Figure 1.

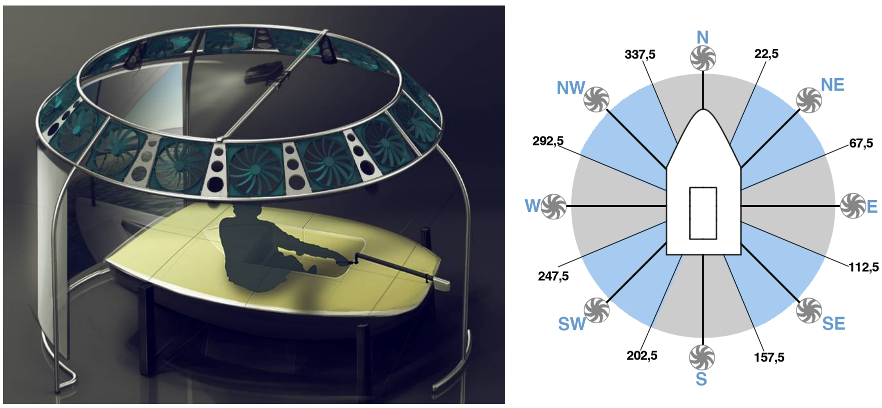

Fig. 1. Sail simulator design (left) and horizontal layout (right)

The vertical tilt of the fans was 45 degrees. The height of the structure was 2000 mm above the surface of the boat, the diameter of the ring was 4000 mm. Audio was provided by the means of 5.1 surround speakers. In terms of hardware, the simulator setup comprised a Laser boat mounted in front of the screen on which the digital simulation was projected. The simulation was controlled by a physical rudder and a mainsheet line – the latter included haptic force feedback.

The software set-up is depicted in Figure 2, consisting of a commercial simulator game Sail Simulator 5[b] . Labview and an Arduino microcontroller were used to control the fans, which electrical interface was extended with MOSFETs to handle the speed of the Fans with pulse-width modulation.

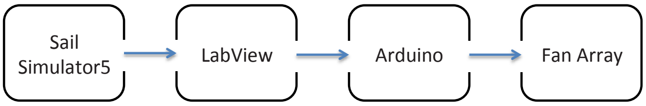

Fig. 2. Sail simulator data flow

3. Evaluation

3.1 Procedure

The procedure consisted of two tests. The first one required participants to use the Sail Simulator and perform maneuvers like hiking, tacking and jibing and to sail in a straight line for approximately 30 seconds. After that a short interview was held to discuss the experience and its realism.

During the second test, the participants performed the same maneuvers again, but with the wind simulation set-up turned on. After the second test was conducted, another short discussion was conducted to obtain the impressions and opinions. Half of participants were presented with test setup in reversed order – first with wind simulation, and then without. This was done in order to prevent the possibility that knowing that one more sensory experience was added could trick participants into thinking that it was more immersive (technology bias).

Fig. 3. Impression of the setup during tests

b http://www.sailsimulator.com/

Finally, the participants were asked to fill a reduced form of the standard Presence Questionnaire [10], stated in Table 2.

Table 2. Adapted presence questionnaire

Number	Questionnaire Item
1	How much were you able to control events?
2	How natural did your interactions with the environment seem?
3	How aware were you of events occurring in the real world around you?
4	How consistent were your experiences coming to your different senses?
5	How much delay did you experience between your actions and expected outcomes?
6	To what degree did you feel confused or disoriented when the experiment ended?
7	How quickly did you adjust to the virtual environment experience?
8	Where you involved in the experimental task to the extent that you lost track of time?

3.2 Participants

Out of 10 participants 7 were male, 3 female. Average age was 23.4. All had at least 50 hours of sailing experience – 5 Participants have sailed since early age (7 or 8), 3 of them work as sailing instructors.

3.3 Results

The questionnaire results show improvement of immersion levels, as shown in Table 3. Interview responses of two test groups (primed with wind simulation or plain Sail simulator) differ. Both test groups admitted the realism of experience in general was remarkably high. All participants that started without wind simulation were excited about the simulator, saying that it worked well and felt surprisingly immersing. Four out of 5 explicitly expressed impression that it was hard to figure out the directions of the wind, as there were no indications on the screen except for telltales on the sail. Two of 5 soon after the test started requested the fans to be turned on.

Table 3. Questionnaire results for experiment primed with wind simulation (Qx) and without (Qx W), Answer scales were from 1 to 6; Presence questions in Table 1

Participant	**Q1**	**Q1 W**	**Q2**	**Q2 W**	**Q3**	**Q3 W**	**Q4**	**Q4 W**
1	6	6	5	4	3	3	5	4
2	6	6	5	1	5	2	6	3
3	4	2	5	2	5	4	4	2
4	4	3	6	2	2	2	5	2
5	4	2	5	2	3	1	4	2
6	4	2	5	4	4	5	3	4
7	4	3	4	2	3	3	4	4
8	4	4	4	3	3	3	3	3
9	5	3	5	3	3	5	5	4
10	5	3	4	3	2	2	5	3
Mean	4.60	3.40	4.80	2.60	3.30	3.00	4.40	3.10
SD	0.84	1.50	0.63	0.97	1.06	1.33	0.97	0.88

Participant	Q5	Q5 W	Q6	Q6 W	Q7	Q7 W	Q8	Q8 W
1	5	5	4	4	5	4	6	6
2	6	3	4	2	6	3	5	4
3	1	1	1	1	4	3	3	2
4	3	4	5	3	4	4	5	5
5	6	2	5	2	5	2	5	2
6	1	4	2	3	2	4	4	5
7	5	5	1	1	5	3	4	3
8	4	4	3	5	4	3	3	3
9	4	4	5	4	5	3	5	4
10	6	6	2	2	4	4	6	6
Mean	4.10	3.80	3.20	2.70	4.40	3.30	4.60	4.00
SD	1.91	1.48	1.62	1.34	1.07	0.67	1.07	1.49

Participants who started with wind simulation provided more critical feedback on its technical implementation. Four of five stated that wind simulation did improve the experience, but they were focusing on visual clues from the simulator to find out the direction of wind. During the second run, all of the participants expressed that they lacked the wind simulation, and that that it was helping them to orient, but they were not consciously aware of it. Such difference implies that wind simulation indeed improves the sailing simulator experience, though for first-time users it appears not realistic enough.

The participants mentioned three main improvements:

1. Almost all participants stated that airflow has to be stronger, either by means of larger amount of air (more fans, or more fans turned on), or by means of higher air flow speed.

2. Increasing the resolution of wind directions in front; as during sailing upwind the provided directions of the wind are imprecise and create a wrongful impression of wind direction.

3. The current sail simulator engine does output a steady wind from a fixed direction. It would be more realistic to host random wind gusts and abrupt wind direction changes (within +/-15 degrees).

4 Conclusions and future work

In this article an experimental sail simulator setup was presented to test the influence of wind on presence. It included a real boat mounted to a static platform equipped with 8 fans. The simulation included an advanced sail simulator engine that controlled both projected graphics as well as the fan array, while the athlete could interact with main sheet and rudder. Ten participants with sailing experience were involved in testing the influence. Findings show that the wind has influence on the presence of the sailors. We will continue to use the implementation in subsequent developments of the sail simulator setup, engaging Olympic and Paralympic athletes.

For further research on this subject several factors could be enhanced or improved:

- A higher airflow displacement could create a higher awareness of the user. In order to get a better understanding of different perceptual thresholds, the speed of the wind could be tuned to a perfect optimum.
- The fans and especially the pulse-width modulation produced high-pitched sounds that should be minimized. As is, participants used this artefact, sometimes unconsciously, to determine wind direction.
- The original design had 16 fans, we have yet to determine whether this angular resolution will improve from the current 8. Based on our preliminary tests, this should not have a large effect
- During real life sailing, wind is mostly sensed as cold due to environmental aspects. Wind temperature is also something to be considered of having an impact on the user experience.

Acknowledgements

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